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FINAL TECHNICAL REPORT: NASA Grant #NGR 05-004-099

TITLE: EFFECT OF ALTERED GRAVITY ON TEMPERATURE REGULATION IN MAMMALS
[Investigation of Gravity Effect on Temperature Regulation in Mammals]

PRINCIPAL INVESTIGATORS: B. A. Horwitz
J. M. Horowitz

INSTITUTION: University of California
Department of Animal Physiology
Davis, California 95616

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CONTENTS:

	Page
I. General Objectives	1
II. Procedures Followed	1
III. Nature of Neural Controller	1
A. Summary of Results.	1
B. Conclusion.	1
IV. Thermoregulatory Responses at 2G vs 1G.	2
A. Summary of Results.	2
B. Conclusions	3
V. Extension of 2G Results to Other G Fields	3
A. Summary of Results.	3
B. Conclusions	4
VI. Final Remarks	4
VII. Publications Crediting Grant.	4
VIII. Appendix Items	
(Reprints of Recent Papers)	

(NASA-CR-157570) EFFECT OF ALTERED GRAVITY
ON TEMPERATURE REGULATION IN MAMMALS:
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I. GENERAL OBJECTIVES OF THE PROJECT

The aim of this grant was to determine how well the mammalian thermoregulatory system regulates under the combined stressors of altered gravity and ambient temperature. Specifically, the grant proposed to compare the dynamic as well as static characteristics of the thermoregulatory system at hypergravity and at 1G.

II. PROCEDURES THAT WERE FOLLOWED IN PURSUIT OF PROJECT OBJECTIVES

The work performed on this grant during the 2.5 years of its funding was divided into several phases. The initial work involved characterizing the nature of the neural controller of temperature in rats at 1G and evaluating chronic implantation techniques for the monitoring of appropriate parameters at hypergravic fields. This initial stage was followed by a period in which we compared the thermoregulatory responses of cold-exposed rats at 2G to those at 1G and formulated a computer model able to simulate the thermoregulatory system in the rat. The final phase of the study involved an extension of our observations at 1 and 2G to acceleration fields of 1.5, 3.0 and 4.0G and the modification of the computer model for application to altered gravity conditions.

III. PHASE I -- Ground-based data regarding the nature of the neural controller of temperature in rats.

A. Summary of Results. Male, Long-Evans hooded rats were chronically implanted with internal electromyographic (EMG) leads, thermistors, and ground wires so that shivering activity and a variety of temperatures could be monitored. In addition, during the experiment concurrent noninvasive measurements of oxygen consumption and core temperature were obtained. Thus the rats were instrumented for monitoring core and hypothalamic temperatures as well as shivering and nonshivering thermogenesis in response to decreased ambient temperature. The results of these studies provide ground-based information on the dynamic characteristics of the thermoregulatory controller at 1G, information relevant for interpreting space-flight data. Among the results obtained are the following:

1. Chronic implantation of the thermosensors (hypothalamus, spinal cord, core) and EMG electrodes had no apparent effect on the ability of the rat to respond appropriately to cold exposure at 1G.
2. Changes in temperature of spinal cord receptors influenced shivering with no effect on nonshivering thermogenesis.
3. Changes in hypothalamic temperature influenced nonshivering heat production with no apparent effect on shivering.
4. Hippocampal theta rhythms were evoked upon thermal stimulation of the animal (in these experiments, rabbits were utilized).

B. Conclusions Drawn

1. Signals from three major thermoreceptor locations in the rat (skin, spinal cord, hypothalamus) do not appear to be integrated in an identical manner by the neural controllers for shivering and nonshivering heat production at 1G. That is, sorting at the level of the neural controllers seems to occur.

2. The hippocampus appears to be involved in the mammal's response to cold ambient temperatures -- most likely serving to elicit thermoregulatory behavioral responses (as opposed to the heat generating responses evoked by the hypothalamus).

IV. PHASE II -- Comparison of the thermoregulatory responses of rats exposed to cold at 2G versus those at 1G.

A. Summary of Results. Using the 4.5 ft. radius centrifuge at U.C. Davis, rats were exposed to 2G fields for periods up to 7 hours. Some of these rats were maintained at room temperature under controlled laboratory conditions (Group A); others were cold acclimated (Group B) under controlled conditions; a third group (C) was housed for 1 week in a relatively stressful environment involving elevated and intermittent noise, continuous light, and varying ambient temperatures (15-26°C); and the fourth group (D) was maintained ("acclimated") for 3 weeks in the relatively stressful environment of Group C. The findings from this part of the project include those listed below.

1. Upon initial exposure of all rat groups, there occurred a rapid decrease in colonic temperature, confirming earlier observations of others.
2. This decrease was followed, after about 1 hour, by a slow recovery toward precentrifugation levels, again confirming earlier studies.
3. The initial decrease in colonic temperature was accompanied by decreased hypothalamic and spinal cord temperatures and increased tail temperatures.
4. This initial decrease in colonic temperature was attenuated by inverting the rat during centrifugation.
5. The magnitude of this initial colonic temperature decrease was similar for all rat groups.
6. The dynamic characteristics of the thermoregulatory system were examined by cold exposing the rats for 1 hour while they continued to be centrifuged. This exposure to cold concurrent with centrifugation evoked further decreases in colonic temperatures that were not accompanied by increased tail temperatures.
7. Within the first 7 hours of centrifugation (the maximum time period used in the study) there was no effect of the time of onset of the cold exposure on the magnitude of the temperature decrease.
8. The magnitude of this cold-induced fall in colonic temperature in rats subjected to 2G fields varied in the four animal groups. Specifically, the magnitude of the decrease at 2G was less in those groups already acclimated to a stressful environment than in those that were not so acclimated [i.e., Group B (cold-acclimated) vs. Group A (noncold-acclimated); Group D (acclimated to adverse environment) vs. Group C].

B. Conclusions Drawn

1. The initial fall in temperature occurring with exposure to 2G may be secondary to an effect on the cardiovascular system, as indicated by the increase in tail temperature. That is, this latter change suggests the shunting of warm blood to the tail with increased heat loss to the environment, a response that would not be considered "normal" in terms of thermoregulation. Thus, the response may represent a primary alteration of the cardiovascular system that secondarily affects the thermal responses of the rat.
2. In contrast, the observation that cold-exposed rats at 2G exhibit a decreased ability to maintain colonic temperature appears to reflect an altered ability to generate heat rather than an increased heat loss (since no increases in tail temperatures were seen).
3. The prior state of the animal has a decided effect on its ability to thermoregulate when exposed to cold at 2G.

V. PHASE III — Extension of 2G observations to other hypergravic fields and computer simulation of the system.

A. Summary of Results. These experiments were conducted to determine if the altered ability of rats to maintain colonic temperatures when challenged with a 1 hour period of cold at 2G is proportional to the magnitude of the acceleration field; and if the magnitude of the decreased thermoregulatory ability is related to the onset time of the cold relative to that of acceleration. Instrumented rats were placed on the 4.5 ft. radius centrifuge and exposed to 1, 2, 3, or 4G for 5-7 hours. The 1 hour of cold exposure began 0-3 hours after initiation of centrifugation. The following results were obtained:

1. Whereas 1 hour of cold exposure at 1G caused only a slight decrease in core temperature, 1 hour of cold exposure at hypergravic conditions evoked significant falls in core temperature.
2. The magnitude of the cold-induced temperature drop varied directly with the amplitude of the step changes in gravitational field. In fact, the relationship seems linear and can be expressed by the following equation:

$$\text{Change in colonic temperature} = 2.36G - 0.79 \text{ for } 1\text{-}4G \text{ fields}$$

3. No increases in tail temperature accompanied the cold-induced falls in colonic temperature.
4. Delaying the time of onset of the cold exposure with respect to the onset of the change in gravitational field did not appear to significantly affect the magnitude of the cold-induced fall in colonic temperature.
5. These data were used to formulate a computer simulation, using CSMP, with inclusion of gravity-dependent parameters.

B. Conclusions Drawn

1. The thermoregulatory system appears to be affected immediately after changes in acceleration field.
2. This effect involves inadequate heat generation rather than increased heat loss.
3. The fact that cold induces a decrease in colonic temperature beyond that occurring initially with the onset of acceleration implies that the effect of hypergravity on the thermoregulatory system is not simply an alteration of the set point. Rather, acceleration appears to impair the ability of the neurocontroller to appropriately integrate input signals for body temperature maintenance.

VI. FINAL REMARKS

Work is continuing on the effects of gravity on the thermoregulatory system of mammals and is being supported in part by NASA grant NSG 2234 entitled, "Thermoregulation in Rats: Effects of Hypergravity and of Norepinephrine."

VII. PUBLICATIONS ACKNOWLEDGING NASA SUPPORT**A. Full Papers**

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